

## Glulam Design for Fire Performance

膠合集成材設計之防火表現

Taipei  
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Borjen Yeh, Ph.D., P.E.  
APA – The Engineered Wood Association

## Taiwan Fire Code

- **Fire Code for Wood Construction in Taiwan (木構造建築物設計及施工技術規第九章建築物之防火) was published in November 2008**
- **Dr. Su (蘇鴻奇) presented background info at the last APA Seminar in August 2008**



## Characteristics of Glulam in Fire

- **Wood is an excellent heat insulator**
- **Develops a char layer after fire exposure**
- **Self-extinguishing after fire source removed**
- **Retains significant residual strength after being exposed to fire**



## Glulam vs. Steel



## Glulam vs. Steel



## Fire Rating for Glulam

- Two accepted methods under US Building Codes
- IBC Empirical Method
- NDS Mechanics Based Model



## APA Technical Note

- Provides details of the IBC and NDS methods
- Examples for both methods



## IBC Methodology

- Empirical protocol
- Based on extensive testing in the U.S. and other countries using the ISO 834 fire test protocol
- Beams – 3 or 4 sides exposed
- Columns – 3 or 4 sides exposed

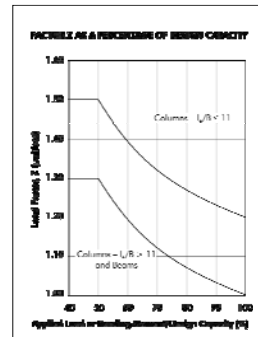


### IBC Methodology for Beams

- Beams exposed on 3 sides  
 $t = 2.54ZB [ 4 - B/D ]$
- Beams exposed on 4 sides  
 $t = 2.54ZB [ 4 - 2B/D ]$
- B = beam width
- D = beam depth
- t = fire resistance in minutes
- Z = load compensation factor  
 = applied load / design capacity



### IBC Methodology

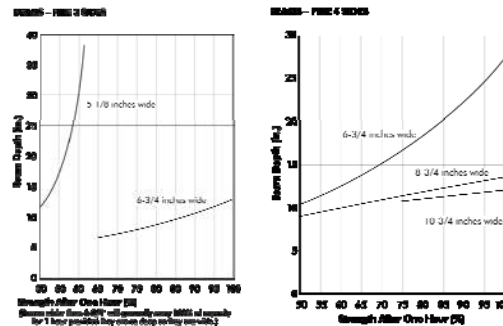


### IBC Methodology for Columns

- Columns exposed on 3 sides  
 $t = 2.54ZB [ 3 - B/2D ]$
- Columns exposed on 4 sides  
 $t = 2.54ZB [ 3 - B/D ]$



### One-Hour Fire Rated Glulam



### One-Hour Fire Rated Glulam

**MINIMUM DEPTH (D) WHICH GLULAM BEAMS CAN BE ADAPTED FOR ONE-HOUR FIRE EXPOSURE**

Beam Width (b)	Depth 3 Sides Exposed (in.)	Depth 4 Sides (in.)
3-1/8"	12	22-1/2
4-3/8"	15-1/2	27
6-3/8"	7-1/2	18-1/2

(b) When 3-1/8 inch width glulam is used for one hour fire-rated beams, load capacity is reduced by about 20% for allowable design load for depths shown in Table 5. Contact AWC for details.

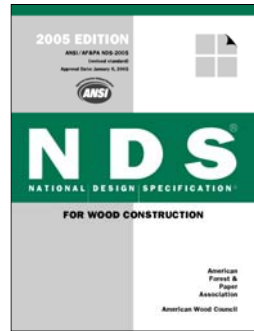
**MINIMUM DEPTH AT WHICH GLULAM COLLUMS CAN BE ADAPTED FOR ONE-HOUR EXPOSURE FOR BEAMS 12" D**

Column Width (b)	Depth 3 Sides Exposed (in.)	Depth 4 Sides Exposed (in.)
6M T1	10-3/4"	13-1/2"
6M T2	6-5/8"	10-1/2"
6M T3	6-3/4"	7-1/2"
6M T4	10-3/4"	10-1/2"

(b) Columns with a nominal width of 6-3/4 inches can be used for one hour fire-rated columns, but load capacity is reduced to about 20% of the allowable design load for depths shown in Table 6. Contact AWC for details.



### 2005 NDS Methodology



- Chapter 16
- Mechanics Based Model
- Supported by empirical data



### 2005 NDS Methodology

- Determine reduced section properties of glulam after fire exposure using effective char layer
- Calculate induced bending stress with reduced section
- Determine the member strength based on tabulated stress x fire adjustment factor (2.85 for bending)
- $F_b \times 2.85 \geq$  calculated induced stress



### 2005 NDS Methodology

		ASD						
		Design Stress or Member Strength Factor	Size Factor <sup>1</sup>	Volume Factor <sup>2</sup>	Flat Use Factor <sup>3</sup>	Beam Stability Factor <sup>4</sup>	Column Stability Factor <sup>5</sup>	
Bending Strength	$F_b$	x	2.85	$C_F$	$C_V$	$C_{Fu}$	$C_L$	-
Tensile Strength	$F_t$	x	2.85	$C_F$	-	-	-	-
Compression Strength	$F_c$	x	2.58	$C_F$	-	-	-	$C_P$
Beam Buckling Strength	$F_{bE}$	x	2.03	-	-	-	-	-
Column Buckling Strength	$F_{cE}$	x	2.03	-	-	-	-	-

- The strength factor brings the fire design to the average breaking strength of glulam



### 2005 NDS Methodology

$$\beta_{\text{eff}} = \frac{1.2\beta_n}{t^{0.187}}$$

Where:

- $\beta_{\text{eff}}$  = Effective char rate (in./hr), adjusted for exposure time, t
- $\beta_n$  = Nominal char rate (1.5 in./hr)
- t = Exposure time (hr)



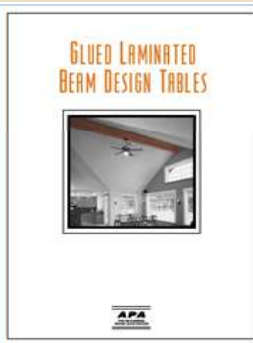
### 2005 NDS Methodology

t	$\beta_{\text{eff}}$
1 hr	1.8 in./hr (45.7 mm/hr)
2 hr	1.58 in./hr (40.1 mm/hr)



### IBC Example: Glulam Beam

- EWS S475 Glulam Design Tables



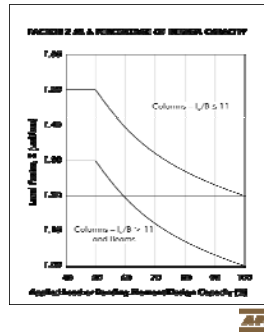
### IBC Example: Glulam Beam

- L = 30 ft simple-span
- TL = 240 lbf/ft (dead + snow load)
- 3-side exposure
- $F_b = 2,400$  psi
- $E = 1.8 \times 10^6$  psi
- $F_v = 265$  psi
- Determine 1-hr fire rated glulam

Depth (in.)	5-1/8-INCH WIDTH											SPAN (ft)			
	8	10	12	14	16	18	20	22	24	26	28	28	28	30	
12	3829	2445	1693	1240	946	660	477	355	270	209	164	131			
13-1/2	4848	3097	2145	1572	1199	944	684	509	389	302	238	191			
15	5987	3825	2651	1942	1483	1160	926	703	537	419	321	256			
16-1/2	7092	4630	3209	2392	1788	1392	1111	906	720	562	446	358			
18	8126	5513	3821	2802	2111	1644	1313	1071	888	723	583	470			
19-1/2	9268	6472	4487	3264	2460	1915	1530	1248	1036	872	743	601			
21	10537	7387	5036	3759	2833	2207	1763	1439	1194	1005	857	738			
22-1/2	11955	8121	5637	4287	3232	2518	2012	1642	1363	1148	979	843			
24	13551	9024	6213	4848	3655	2848	2277	1858	1543	1300	1108	954			
25-1/2	15360	10007	7416	5442	4103	3197	2556	2087	1733	1460	1245	1073			
27	17428	11078	8115	6068	4576	3566	2851	2328	1924	1629	1390	1198			
28-1/2	19814	12292	8863	6726	5073	3953	3162	2582	2145	1807	1542	1329			
30	22598	13544	9644	7416	5594	4360	3487	2848	2366	1994	1701	1467			
31-1/2	25889	14972	10524	8110	6139	4785	3827	3126	2597	2189	1868	1611			
33	28922	16598	11451	8747	6708	5229	4183	3417	2839	2394	2043	1762			

### IBC Example: Glulam Beam

- Try 5-1/8" x 21" (allowable = 266 plf)
  - 240 / 266 = 0.90
  - Z = 1.03
  - t = 2.54 x 1.03 x 5-1/8 x (4 - 5-1/8 / 15) = 49 min.
- NG!**



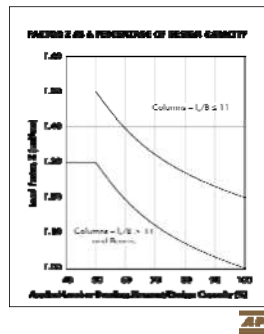
### IBC Example: Glulam Beam

- From design table, choose 5-1/8" x 18" (allowable = 470 plf)

Depth (in.)	5-1/8-INCH WIDTH										SPAN (ft)		
	8	10	12	14	16	18	20	22	24	26	28	30	
12	2629	2445	1699	1240	944	665	477	355	270	209	164	131	
13-1/2	4648	3997	3145	1973	1199	944	684	509	389	302	238	191	
15	5987	3825	3161	1942	1463	1149	926	703	537	419	322	266	
16-1/2	7093	4530	3209	2293	1798	1392	1111	904	725	562	446	368	
18	8124	5513	3821	2803	2111	1644	1313	1071	883	723	582	470	
19-1/2	9148	6472	4487	3244	2440	1915	1530	1248	1036	872	743	601	
21	10157	7287	5204	3759	2823	2207	1743	1429	1194	1005	857	738	
22-1/2	11955	8121	5927	4287	3222	2518	2012	1642	1343	1148	979	843	
24	12551	9024	6713	4848	3655	2848	2277	1858	1543	1300	1108	954	
25-1/2	15340	10037	7413	5442	4103	3197	2556	2087	1734	1460	1246	1073	
27	17428	11078	8115	6068	4574	3564	2851	2228	1924	1629	1390	1198	
28-1/2	19814	12292	8863	6736	5073	3953	3142	2482	2145	1807	1542	1329	
30	22598	13544	9644	7416	5594	4360	3487	2848	2346	1994	1701	1467	
31-1/2	25889	14972	10524	8170	6139	4785	3827	3126	2597	2180	1868	1611	
33	28992	16558	11451	8747	6708	5229	4183	3417	2829	2394	2042	1762	

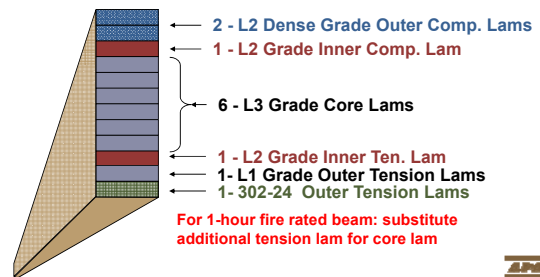
### IBC Example: Glulam Beam

- 240 / 470 = 0.51
  - Z = 1.28
  - t = 2.54 x 1.28 x 5-1/8 x (4 - 5-1/8 / 18) = 61.9 min.
- OK!**



### Typical Glulam Beam Layout

#### 24F-V4 Doug Fir (12 Lamination Example)



### Fire Rated Glulam Layup

#### SIMPLE SPAN LAYUP



### NDS Example: Glulam Beam

- L = 30 ft simple span
- TL = 240 lbf/ft (dead + snow load)
- 3-side exposure
- $F_b = 2,400$  psi
- $E = 1.8 \times 10^6$  psi
- $F_v = 265$  psi
- Determine 1-hr fire rated glulam

Depth (in.)	5-1/8-INCH WIDTH											SPAN (ft)					
	8	10	12	14	16	18	20	22	24	26	28	30	8	10	12	14	
12	3829	2445	1693	1240	946	660	477	355	270	209	164	131					
13-1/2	4848	3097	2145	1572	1199	944	684	509	389	302	238	191					
15	5987	3825	2651	1942	1483	1160	926	703	537	419	322	256					
16-1/2	7092	4630	3209	2332	1788	1392	1111	904	720	562	446	358					
18	8126	5513	3821	2802	2111	1644	1313	1071	888	723	583	470					
19-1/2	9268	6472	4487	3264	2460	1915	1530	1248	1036	872	743	601					
21	10537	7287	5036	3759	2833	2207	1763	1439	1194	1005	857	738					
22-1/2	11955	8121	5937	4287	3232	2518	2012	1642	1363	1148	979	843					
24	13551	9024	6713	4848	3655	2848	2277	1898	1543	1300	1108	954					
25-1/2	15340	10007	7416	5442	4103	3197	2556	2087	1733	1460	1245	1073					
27	17428	11078	8115	6068	4576	3566	2851	2328	1924	1629	1390	1198					
28-1/2	19814	12252	8863	6726	5073	3953	3162	2582	2145	1807	1542	1329					
30	22598	13544	9644	7416	5594	4360	3487	2848	2346	1974	1701	1467					
31-1/2	25889	14972	10524	8110	6139	4785	3827	3126	2597	2189	1868	1611					
33	28892	16558	11451	8747	6708	5229	4183	3417	2839	2394	2043	1742					

### NDS Example: Glulam Beam

- Try 5-1/8" x 15"
- For 1 hr fire rating,  $\beta_{eff} = 1.8$  in./hr
- $b_{1-hr} = 5-1/8" - 2 \times 1.8" = 1.525"$
- $h_{1-hr} = 15" - 1.8" = 13.2"$
- $S_{1-hr} = 1.525 \times 13.2^2 / 6 = 44.3$  in.<sup>3</sup>
- $M_{1-hr} = 2.85 \times F_b' \times S_{1-hr} = 2.85 \times 2,400 \times 0.9437 \times 44.3 / 12 = 23,831$  lbf-ft

Depth (in.)	5-1/8-INCH WIDTH											SPAN (ft)					
	8	10	12	14	16	18	20	22	24	26	28	30	8	10	12	14	
12	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9974	0.9927	0.9799	0.9714	0.9450	0.9150					
13-1/2	1.0000	1.0000	1.0000	1.0000	1.0000	0.9995	0.9967	0.9770	0.9674	0.9405	0.9087	0.8747					
15	1.0000	1.0000	1.0000	1.0000	0.9991	0.9927	0.9734	0.9620	0.9373	0.9030	0.8658	0.8256					
16-1/2	1.0000	1.0000	1.0000	0.9954	0.9857	0.9724	0.942	0.9308	0.9042	0.8613	0.8157	0.7674					
18	1.0000	1.0000	1.0000	0.9867	0.9732	0.9435	0.9124	0.8813	0.8441	0.7956	0.7438	0.6890					
19-1/2	1.0000	1.0000	0.9950	0.9789	0.9474	0.9153	0.8820	0.8480	0.8073	0.7556	0.7012	0.6444					
21	1.0000	1.0000	0.9947	0.9756	0.9420	0.9082	0.8732	0.8360	0.7924	0.7368	0.6786	0.6174					
22-1/2	1.0000	1.0000	0.9926	0.9710	0.9350	0.9000	0.8647	0.8274	0.7820	0.7238	0.6624	0.5985					
24	1.0000	1.0000	0.9882	0.9734	0.9338	0.8973	0.8607	0.8227	0.7763	0.7159	0.6524	0.5868					



### NDS Example: Glulam Beam

- $M_{applied} = wL^2/8 = (240 + 18.7) \times 30^2 / 8 = 29,102$  lbf-ft >  $M_{1-hr}$  (23,831 lbf-ft)
- **NG!**

5-1/8-INCH WIDTH			
Depth (in.)	12	13-1/2	15
Beam Weight (lb/ft)	14.9	16.8	18.7
A (in. <sup>2</sup> )	61.50	69.19	76.88
S (in. <sup>3</sup> )	123.0	155.7	192.2
I (in. <sup>4</sup> )	738.0	1051	1441



### NDS Example: Glulam Beam

- Try 5-1/8" x 18"
- For 1 hr fire rating,  $\beta_{eff} = 1.8 \text{ in./hr}$
- $b_{1-hr} = 5-1/8" - 2 \times 1.8" = 1.525"$
- $h_{1-hr} = 18" - 1.8" = 16.2"$
- $S_{1-hr} = 1.525 \times 16.2^2 / 6 = 66.7 \text{ in.}^3$
- $M_{1-hr} = 2.85 \times F_b' \times S_{1-hr} = 2.85 \times 2,400 \times 0.9266 \times 66.7 / 12 = 35,213 \text{ lbf-ft}$

Depth (in.)	0	3.2	6.4	9.6	12.8	16.0	19.2	22.4	25.6	28.8	30
12	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9954	0.9867	0.9750	0.9614	0.9456
15	1.0000	1.0000	1.0000	1.0000	1.0000	0.9959	0.9872	0.9755	0.9618	0.9460	0.9287
18	1.0000	1.0000	1.0000	1.0000	0.9954	0.9867	0.9750	0.9614	0.9456	0.9287	0.9107
21	1.0000	1.0000	0.9959	0.9872	0.9755	0.9618	0.9460	0.9287	0.9107	0.8916	0.8714
24	1.0000	0.9959	0.9872	0.9755	0.9618	0.9460	0.9287	0.9107	0.8916	0.8714	0.8500
27	1.0000	0.9959	0.9872	0.9755	0.9618	0.9460	0.9287	0.9107	0.8916	0.8714	0.8500
30	1.0000	0.9959	0.9872	0.9755	0.9618	0.9460	0.9287	0.9107	0.8916	0.8714	0.8500



### NDS Example: Glulam Beam

- $M_{applied} = wL^2/8 = (240 + 22.4) \times 30^2 / 8 = 29,522 \text{ lbf-ft} < M_{1-hr} (35,213 \text{ lbf-ft})$
- OK!**

5-1/8-INCH WIDTH					
Depth (in.)	12	13-1/2	15	16-1/2	18
Beam Weight (lb/ft)	14.9	16.8	18.7	20.6	22.4
A (in. <sup>2</sup> )	61.50	69.19	76.88	84.56	92.25
S (in. <sup>3</sup> )	123.0	155.7	192.2	232.5	276.8
I (in. <sup>4</sup> )	738.0	1051	1441	1919	2491



### Example Summary

- The same example,
  - IBC = 5-1/8" x 18"
  - NDS = 5-1/8" x 18"



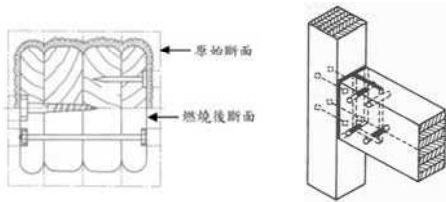
### Connections

- 木構材接合部之設計應注意保護金屬扣件，避免火災持續燃燒期間因受火害之高溫影響，使金屬扣件強度衰減，導致接合功能之喪失。因此若使用金屬扣件接合時，應設置足夠厚度之防火被覆保護金屬扣件，或將接合金屬扣件設置在具防火時效之構材安全斷面內側



### Connections

以金屬扣件連結之木接點應深入至防火時效後之殘餘斷面



### Fire Safety of Light Frame Construction



### Fire Safety of Light Frame Construction



Hybrid construction with 1<sup>st</sup> story of steel or concrete supporting 2-4 stories of wood framed construction



### Light Frame Construction

- IBC permits calculation of fire performance based on component additive method
- Evaluated in accordance with ASTM E119 assembly tests
  - Wall assemblies
  - Floor assemblies
  - Roof assemblies



### IBC Component Method \*

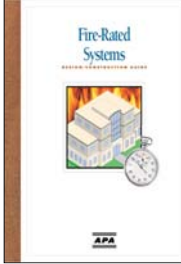
Example: Assume wood framed wall

2x4 studs at 16" on center	20
15/32" wood structural panel	10
1/2" gypsum wallboard	15
glass fiber wood batt insulation	15
<b>Total =</b>	<b>60</b>


\* Section 721.6 of IBC  
Fire-Resistance of Wood Assemblies



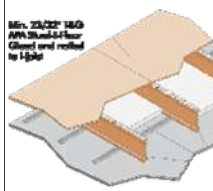
### Fire Rated Systems



**WOOD-BEARING EXTERIOR WALL SYSTEMS**  
Based on IBC, Design No. L204 by Underwriters Laboratories Inc. (UL) Fire Institute Directory.  
With Steel Studing (Stud or other suitable 1/2" hole-percentage type)  
2x4 Type C gypsum sheathing  
Min. 15/32" thick Area Sheathing (Minimum 1 OSB or plywood)  
Classifier Institute (ICC)  
2x4 wood stud @ 16" or 24" o.c.



**APAC W88-3.3 SHEATHING**  
Min. 2x4 @ 16" o.c.  
APA 2x4 wood stud  
Classified wood stud  
to 1-hour



Min. 5/8" Type C gypsum wallboard top  
Min. 1-1/2" mineral wool batts (2.5 gcf)  
Min. 5/8" wood 1-joint spaced studs, 24" o.c.  
Min. 3-1/2" x 1-1/2" Sengen  
For additional details, see APAC W88-3.3 (www.apawood.org)



### Hundreds of Publications

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美國工程木材協會

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# Questions?

The screenshot shows the APA website interface. At the top left is a navigation menu with links for PRODUCTS, PUBLICATIONS, APPLICATIONS, EDUCATION, NEWS & EVENTS, MEDIA TOPICS, MEMBER DIRECTORY, and APA PROGRAMS. Below this is a main banner for 'APA Performance Rated Rim Boards' with a sub-headline: 'Engineered for greater dimensional stability, increased structural reliability, and less checking and splitting than sawn lumber.' Below the banner is a sub-header: 'THE LEADING RESOURCE FOR INFORMATION ABOUT ENGINEERED WOOD PRODUCTS'. The main content area is divided into four columns: NEWS, NEW PUBLICATIONS, SUPPORT, and FEATURED APA SITES. The NEWS column lists several articles with dates and titles. The NEW PUBLICATIONS column lists technical guides and manuals. The SUPPORT column describes the APA Help Desk and Field Services. The FEATURED APA SITES column lists external resources like APAlead.org and PerformancePanels.com.

NEWS	NEW PUBLICATIONS	SUPPORT	FEATURED APA SITES
02.08.2009 APA Launch Efficient Structural Glue Connect	06.11.09 Product Guide Performance Rated Siding	APA Help Desk answers to your questions about the specifications and applications of engineered wood products and systems. Call 203-620-7400 or 202.828.00	APAlead.org Over 100 free CAD details for wood frame construction
02.04.2009 APA Publishes Three New Trail Smoothing Brochures	05.13.09 Data File: APA Performance Products in Europe Canadian/Latin Market Design	APA Field Services APA Field Services are available throughout North America	PerformancePanels.com Details about non-ferrous metal applications and attributes of panels
01.05.2009 Wood Products Market Outlook Now Available From APA	05.13.09 Product Reference Literature CD		WoodUniversity.org
12.23.2008 Wood Construction Task 12: The Garage for Reinforced Concrete	05.13.09 Engineers Reference Literature CD		